MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2017/2018

EEE2056 – PHYSICAL ELECTRONICS
(All sections/Groups)

2 MARCH 2018
9.00 a.m. - 11.00 a.m.
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 6 pages with 4 Questions only.
2. Attempt **All** questions. All questions carry equal marks and the distribution of the marks for each question is given.
3. Please write all your answers in the Answer Booklet provided.

Useful constants and coefficients:

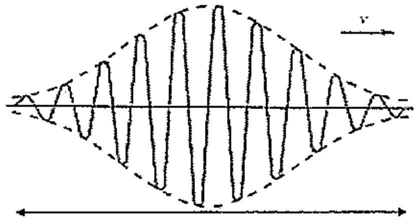
Physical Constants

Boltzmann's constant (k)	1.3807×10^{-23} JK^{-1} 8.617×10^{-5} eVK^{-1}
Planck's constant (h)	6.626×10^{-34} Js
Thermal voltage@300K kT/e kT	0.0259 V 0.0259 eV
Electron mass in free space $\left(m_e\right)$	9.10939×10^{-31} kg
Electron charge $\left(e\right)$	1.60218×10^{-19} C
Permeability of free space $\left(\mu_0\right)$	$4\pi\times10^{-7}$ Hm^{-1}
Permittivity of free space of free space $\left(\varepsilon_0\right)$	8.85×10^{-12} Fm^{-1}
Avogadro's number $\left(N_A\right)$	6.022×10^{23} atoms/mol

Question 1

(a) (i) The uncertainty in the microscopic world is a logical consequence of the dual behavior of matter. Briefly describe the Heisenberg uncertainty principle and the principle of wave-particle duality using the de Broglie equation. [6 marks]

(ii) Figure Q1(a) describes a wave packet, explain how the wave packet concept can be used to represent a particle.



Δx

Figure Q1(a) [4 marks]

(b) A beam of electrons travel from the left to a potential step barrier V_0, can be described by the Schrödinger wave equation, $-\frac{\hbar^2}{2m}\frac{\partial^2\psi(x)}{\partial x^2}+V(x)\psi(x)=E\psi(x)$, as shown in Figure Q1(b). Assume each particle having an energy $E < V_0$.

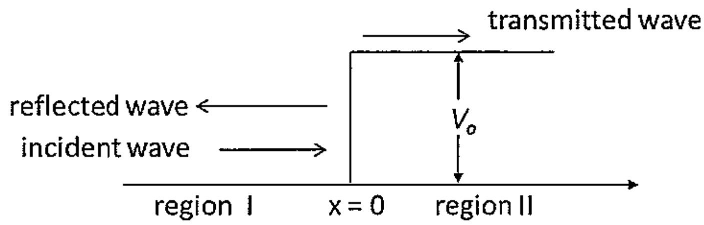


Figure Q1(b)

(i) Write the Schrödinger wave equations for the electron motion in region I and II. [4 marks]

(ii) What are the boundary conditions at $x = 0$? [2 marks]

(iii) Write the solution of wave functions in region I and II. [4 marks]

(iv) Sketch the probability distribution of electron in region I and II. Explain your diagram. [2 marks]

(v) Briefly describe the application of tunneling effect in scanning tunneling microscope. [3 marks]

Continued....

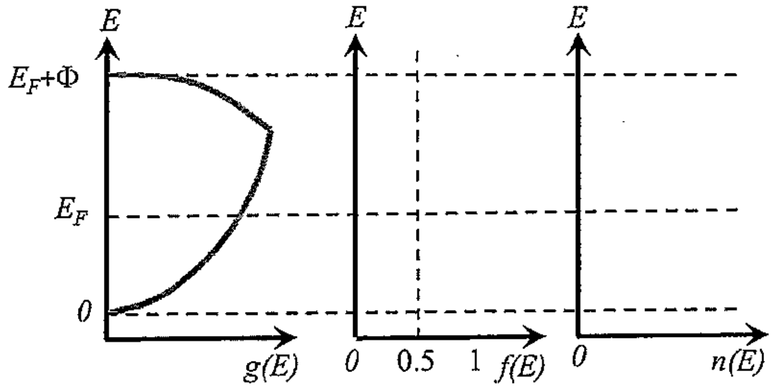
Question 2

(a) State and briefly explain the following two probability functions determining the distribution of particles among available energy states:

(i) Maxwell-Boltzmann probability function [3 marks]

(ii) Fermi-Dirac probability function [3 marks]

(b) Figure Q2(b) shows the density of states, *g(E)*, in a metal from zero energy to Fermi energy plus its work function, $E_F + \Phi$. In your answer script, sketch the Fermi-Dirac distribution function for a finite temperature (T > 0 K) and the distribution of electrons, *n(E)*, with respective to its density of states, *g(E)*. Briefly explain your answers.



[6 marks]

Figure Q2(b)

(c) Explain why at high energy states, where $E >> E_F$, the probability function of electrons in a metal approaches the Maxwell-Boltzmann distribution of neutral gas. [3 marks]

(d) The Fermi energy of electrons, E_F, in a metal at 300 K is 6.5 eV. The electron drift mobility from Hall effect measurements, is 32 $cm^2V^{-1}s^{-1}$.

(i) Determine the speed of electrons with energies around the Fermi level E_F in the metal? [3 marks]

(ii) Determine the average thermal speed of electrons if they behaved like an ideal gas. [3 marks]

(iii) How many times is the speed of part (d)(i) larger than part (d)(ii)? Comment on your result. [2 marks]

(iv) Calculate the mean free path of electrons at E_F. [2 marks]

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Question 3

(a) The energy band diagram of a semiconductor is shown in Figure Q3(a) for the first conduction band and valence band. Using this diagram to answer the following questions:

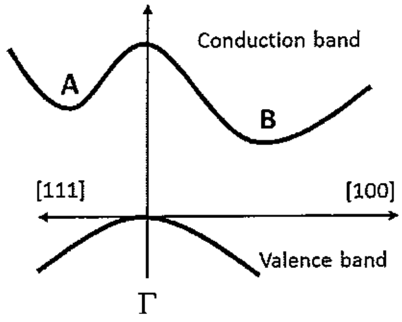

Figure Q3(a)

(i) Is the semiconductor energy gap direct or indirect? Explain. [2 marks]

(ii) Explain which is lower, the effective mass of electron in A-valley or B-valley? [3 marks]

(iii) The electron-hole pair recombination mechanism in this semiconductor involves a recombination center. With the aid of diagrams, explain the electron-hole pair recombination processes. [5 marks]

(b) A silicon crystal is doped with donor atoms to a concentration of 2.0×10^{16} cm^{-3}. Given that the energy bandgap E_g = 1.12 eV, intrinsic carrier concentration $n_i = 1.5\times10^{10} cm^{-3}$, and assume complete ionization of donor atoms at room temperature.

(i) What are the concentrations of electrons and holes in silicon at 300 K? [4 marks]

(ii) The temperature dependence of intrinsic carrier concentration in a semiconductor is given by $n_i = (N_C N_V)^{\frac{1}{2}} \exp\left(-\frac{E_g}{2kT}\right)$, where N_C and N_V are the effective density of states at the conduction and valence band edges, respectively. At what temperature are the intrinsic- and extrinsic-carrier concentrations equal in Silicon? Assume that the energy band gap remains constant. [5 marks]

(iii) With the aid of simple energy diagrams, describe how the N-doped silicon becomes an intrinsic semiconductor at high temperatures. [6 marks]

Continued....

Question 4

(a) Consider two isolated P-type and N-type semiconductors as shown in Figure Q4(a) are brought together to form a PN junction. Sketch the energy band diagram for the PN junction at the equilibrium condition and show the Fermi level throughout the junction in relation to the conduction and valence band edge. Briefly explain your diagram.
[5 marks]

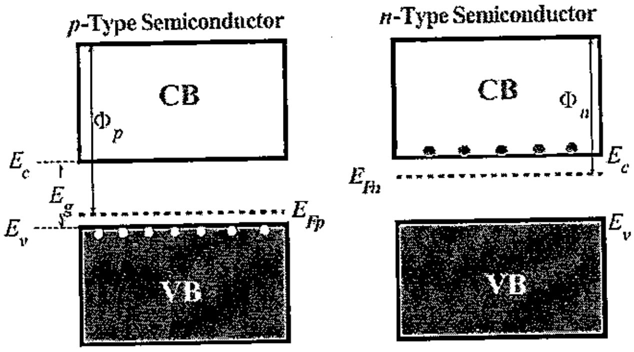

Figure Q4(a)

(b) A long-base PN junction diode has an abrupt junction with uniformly doped regions. The P-side has a resistivity of 1.2×10^{-2} Ωm and the N-side has a resistivity of 0.5×10^{-2} Ωm. Given that mobility of electron and hole are $\mu_n = 0.35$ m²/Vs and $\mu_p = 0.17$ m²/Vs, respectively and $n_i = 2.3\times10^{19}$ m^{-3} at 300 K.

(i) Determine the majority carrier concentration in P- and N- sides. [6 marks]

(ii) Calculate the built-in voltage of the diode. [3 marks]

(iii) Calculate the concentrations of minority carriers at the edges of the P- and N- depletion regions with a forward bias of 0.27 V. [6 marks]

(c) With the aid of a simple energy band diagram, explain the Zener effect in a heavily doped PN junction diode under reverse-biased. [5 marks]

End of the paper